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OPTIMIZATION OF SCRAP REDUCTION IN CONTISEAL'S PROCESS

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Optimization of scrap reduction in ContiSeal's process

Master Thesis

by

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Performed at

ContiSeal

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Abstract

Tires have evolved in several aspects since they were first invented back in 1888; they are being the object of continuous studies to improve the fabrication process and to improve performance and functionalities. Recently, a new plant by Continental, the ContiSeal, began the production of tires with an innovative functionality, an inner sealing layer minimizes air loss when tire is punctured by objects up to 5 mm in diameter.

However, along the production and application of this sealant material there is generation of scrap, particularly during the start up of the twin-screw extruder and sealant application in the tires. Since there is no possibility of reuse this material, this problem is a major challenge. It is therefore the purpose of this project reducing the scrap generation and to study the conditions of reuse it.

Concerning the start up of the twin-screw extruder two variables were examined, barrels temperature and extruder throughput. Optimizing these variables it was possible to achieve a scrap generation reductions of 70 %. The scrap storage for further reuse was also addressed; the storage time and storage temperature were determined.

It was concluded that a reduction and a reuse of the scrap produced are possible, with a final total cost reduction of €7425 per year, although this is only the beginning of what could be an improvement in scrap reduction process.

Key-words – scrap, extruder, sealant, tire, optimization, reduction, reuse

Resumo

O pneu tem evoluído em diversos aspetos desde que foi inicialmente criado em 1988; sendo alvo constante de estudos para melhoria do processo de construção e aumento de desempenho e funcionalidades. Recentemente, uma nova unidade da Continental, ContiSeal, começou a produzir pneus com uma função inovadora, uma camada selante interna capaz de minimizar a perda de ar aquando da perfuração do pneu por objetos com diâmetro inferior a 5 mm.

Contudo, durante a produção e aplicação deste material selante há formação de desperdícios, nomeadamente no arranque da extrusora de fuso-duplo e na aplicação do selante no pneu. Visto que não há possibilidade de reutilizar este material, este problema torna-se um grande desafio. Sendo deste modo, o tema proposto para este projeto a redução dos desperdícios produzido e o estudo da condições de reutilização.

Referente ao arranque da extrusora de fuso-duplo, duas variáveis foram analisadas, temperatura dos barris e caudal de saída da extrusora. Otimizando estas variáveis foi possível uma redução na produção de desperdícios em cerca de 70%. O armazenamento de desperdício para futura reutilização foi também abordado, o tempo de armazenamento e a temperatura de armazenamento foram determinados.

Concluiu-se que uma redução e reutilização dos desperdícios produzidos é possível, com uma redução de custos total final de 7425€ por ano, contudo isto é apenas o início do que poderá ser uma melhoria no processo de redução de desperdícios.

Palavras-chave: desperdício, extrusora, selante, pneu, otimização, redução, reutilização

Statement

I declare, on oath, that this work is original and that all non-original contributions were properly referenced with identification or the source.

Index

List of Figures

List of Tables

Glossary

List of Acronyms

TSE - Twin-screw Extruder

TBPB - Tert-butyl peroxybenzoate

BPO - Di-benzoyl peroxide

LTL - Lower Limit

LAL - Lower Action Limit

UAL - Upper Action Limit

UTL - Upper Limit

QDO - Quinone Dioxime

1 Introduction

1.1 Framework

Usually considered as a simple rubber object present in vehicles, however, a tire involves a lot of technology. One of the largest tires producers is Continental, with a number of 200,000 employers and located in 53 countries, where is structured in five divisions: Chassis and Safety, Powertrain, Interior, Tires and ContiTech.[1] The major focus of this company is the increase of performance in production and tire development, where in 2008 a new plant arises, called ContiSeal, with the purpose of produce a self-sealing tire. This is a very simple and effective process, which in a normal tire is applied a viscoelastic and adherent product in the internal part, named sealant. This product is made up of a mixture of two components, Component A and Component B, avoiding loss of air when objects with a diameter of less than 5 mm puncture the tire.

Component A is produced in a twin-screw extruder, where rubber compound, polybutene and paraffinic oil are mixed, while Component B is a mixture of organic peroxides and polybutene, produced in a mixing tank. The joined of these two components happen in a mixing chamber in the sealant application device, called Robot.

It has recently emerged on this plant a new product, known as ContiSilent, wherein to a normal tire is apply about 1/5 of sealant, in comparison with a sealant tire, follow by a layer of foam, isolating the noise by about 9 decibels.

However, despite the extensive development and advancement of the plant, during the process there is production of scrap material, in start up of the twin-screw extruder, production of Component A, and in sealant application in the tires, with no possibility of reuse this scrap generated.

In Lousado, Portugal, is located one of the two plants of the Continental's group that produce and apply this product, where it was developed the proposed project with the objective of reduce and study the reuse of scrap material in ContiSeal process. For that, it was study the two sources of scrap available in the plant, as previously stated, start up of the twin-screw extruder and sealant application in the tires. In the first case, was evaluated the effect of two variables on the two ContiSeal extruders, barrels temperature and throughput, while in the second case was made an analysis for how long the sealant could be heated without loss of properties, and afterwards reuse this material. The material needs to be constantly heated due to its transportation, otherwise will be very difficult to do it.

1.2 Project Goals

Despite a self-sealing tire being a huge benefit for the user, the process that involves it, is not efficient. During its course, there are large quantities of scrap produced that could be avoided or reused. So, the initial purpose for this project was to reuse the scrap material produced in ContiSeal process. However, reuse this scrap material would be impossible, with no possibilities or ways to reintroduce it in the extruder or reapply it in the tires.

Thereafter, was chosen to reduce the generation of scrap during the start up of the extruder and to study the conditions to reuse the scrap produced in sealant application.

1.3 Work Contributions

Having as objective the study of reduction and reuse of scrap produced, as above stated, through the analysis in the project it was proven to be not only possible reuse the scrap, but it is also possible an process optimization, in the case of the extruders, with no need for a reuse process. Beside this, this will contribute to an increase in the process efficiency.

1.4 Thesis Organization

This thesis is organized in seven chapters, with a simple explanation of each one.

1. **Introduction –** Briefly information about ContiSeal process and the work done in this thesis.
2. **State of the art –** Description of twin-screw extruder application and process as well as sealant used in the tires.
3. **Experimental** – Presents the operation conditions and the procedure used along this thesis.
4. **Results and Discussion –** Exhibition of the results and their discussion.
5. **Conclusion –** Presents the conclusions about the accomplished results.
6. **Project Assessment –** Information about the achievement of the proposed objectives, limitations and suggestions for future work.
7. **Bibliography –** References used over this thesis.

2 State of the Art

2.1 Twin-screw Extruder

Twin-screw extruders, known as TSE, are used in food, pharmaceutical products, plastics and rubber production, due to its many advantages. Among them are the feed and mixing ability compared to the single-screw extruder. The extruders used in this project are TSE, where it is mixed rubber compound, Masterbatch, with three polybutene downstream feeding and one paraffinic oil downstream feeding, obtaining in the end the Component A.

Twin-screw Extruder equipment components is basically composed by a drive, that is the motor that keeps the screw working, feed, where the raw materials entry, screw, barrel heaters and coolers through the extruder, die, where the final product comes out and the controls panel. Each equipment component can vary from extruder to extruder, depending on the ultimate objective. However, the screw is the most important equipment component, in Figure 1 is shown the screw design of the TSEs used in ContiSeal, as well as the screw geometry and number of barrels, twelve of them.

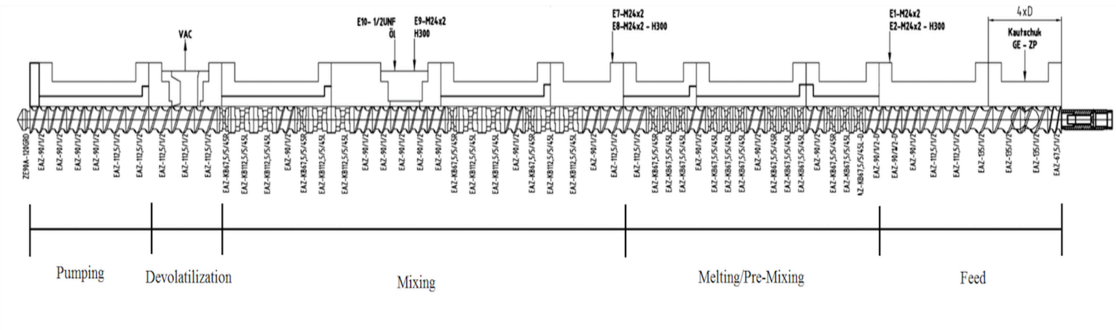

Figure 1 – Screw design of the TSE used in ContiSeal's process (adapted from [2])

The rotate direction is co-rotating and anticlockwise, showing different elements along the design. These elements are responsible for the transport and mixing of the mixture, and are classified into conveying elements, Figure 2, and mixing elements, Figure 3, and besides that, they are placed in a way to ensure the best material homogenization.

Figure 2 - Conveying elements (extracted from [3])

Figure 3 - Mixing elements (extracted from [3])

The conveying elements are represented by two numbers, pitch and length, wherein the pitch represents the screw element length required for a given flight to make on complete revolution around the element. The first screw element is normally a low-pitch, short element, which prevents feed from flowing backward. The second element is a high-pitch element, providing open space for the mixture, after that normal conveying elements are used to convey the feed material to the rest of the extruder. As can be seen in Figure 1, the screw stars with a element length of 67.5 mm, going to a element length of 135 mm, 112.5 mm and finishing in a normal element length of 90 mm. Besides these characteristics, the conveying elements are left-handed, transporting the material from the feed throat toward the die.

The mixing elements, called kneading blocks, have disks in different spatial configuration around the element, and are represented by three numbers. A 45/5/30 kneading block has the second disk rotated 45º from the first disk, the third disk rotated 45º from the second and so on. The other two numbers are the total of disks, five, and the length of it, 30 mm.[3] The higher the angle between the disks, stagger angle, greater will be the kneading action, but this results also in a pressure drop over the kneading element, Figure 4.

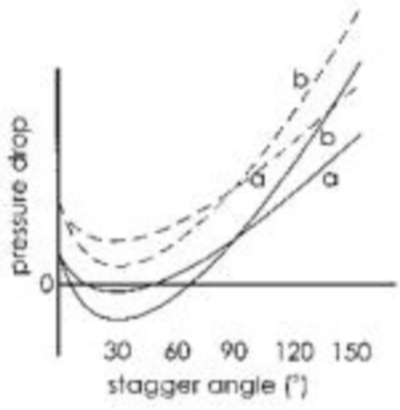

Figure 4 – Relation between pressure drop and stagger angle. a) low rotational speed; b) high rotational speed,; (——) low throughput; (-----) high throughput (extracted from [4]).

In addition, the higher the stagger angle the greater the open area allowing backflow, leading that the last mixing element has to be reverse, right handed, follow by a conveying element, allowing the pressure increase and material flows in right way, feed throat to die.[4] Given these facts, the screws used in both ContiSeal extruders, for every two mixing elements, there is a third reverse mixing element, followed by a conveying element. The stagger angles of the mixing elements are 67.5º and 112.5º, and all elements have five disks.

After the screw elements analysis, the extruder can be broken down into six distinct sections, Figure 1. The first area is the feed, where the screw has low-pitch conveying elements follow by higher-pitch elements. After that, there is the melting and pre-mixing, where the first downstream polybutene is feeding and screw begins to have mixing elements. In the end of this area, conveying elements lead the mixture to the mixing section, where mixing elements have higher stagger angles allowing a better mixing, as well as the second and third downstream polybutene feeding occurs in this section. Then, conveying elements take the mixture to the devolatilization section, used to remove air, moisture, and volatiles prior to the die. Ending with pumping section, which the mixture in high-pitch screw element is gradually compressed by the lower-pitch elements to fill the melt channel, and leaving through the die.[3]

Besides the screw design, another variables influence the final mixture, like screw speed, throughput, feed rate, barrels temperature, viscosity of raw materials, specific energy and the pressure.

Throughput and screw speed in most extruders, are independent variables but related. To constant throughput, increase the screw speed leads to a poor mixing and a specific energy increase, due to the decrease in degree of fill. For constant screw speed, increase the throughput results in a poor mixing too, because the residence time decreases, and the material will not be enough time in the extruder, however this results in a decrease of specific energy. The relationship of these variables can be changed through a regression line, where increase or decrease the slope, will give different values for screw speed, depending on the throughput value, since as in this study we only could control the throughput. As the feed rate, is depending on throughput, a higher throughput value leads to a higher feed rate, and as in previous case, its only possible to control the throughput value.[5]

About the barrels temperature, the influence is shown in material viscosity and in mixing area. Higher the barrels temperature, easier will be the mixing, however, it can also obtain a final product too liquid due to the high temperatures. Increase the temperature, also causes a decrease in specific energy, since it needs less energy to process the mixture. In some cases, an increase can lead too to higher viscosity, due to the pre-crosslinking reaction, depending on the raw materials that are used.

Internal pressure is a value that can be controller and it is always kept constant, taking into account only when the throughput increase, will result in higher pressures. However, the die pressure it is not possible to control, and varies as the throughput also varies.

The specific energy of the extruder is related to how much material can be processed, giving by the ratio between drive motor power with feed rate. With an increase in the feed rate, the required drive motor power will be higher, as well as the screw speed, leading to a better processing of the material and a lower specific energy. Therefore, to lower specific energy values, the mixing will be better.[6]

These parameters can wide vary from extruder to extruder and even being controlled by different ways, wherein for optimizing the process, all variables must be considered together with the material properties, and with screw design, in order to get a good mixture and the final product desired.

2.2 Component A

Component A is a mixture of rubber compound, called Masterbatch, Table 1, polybutene and paraffinic oil. Masterbatch enters at 75 ºC and inside the extruder contact with three polybutene downstream feeding at 53 ºC and one paraffinic oil downstream feeding. Along the extruder, the temperature profile vary from 50 ºC to 125 ºC, since during the mixing there is heat released and the screw elements are different, influence this way the temperature profile. The final temperature, 125 ºC, corresponds to the die temperature, while the internal pressure is 9 bar in one extruder, and 10.5 bar in the other one. At the end, Component A is forwarded to four accumulators, with a capacity of 200 liters each, at 120 ºC, which is the temperature that occurs the reaction between Component A and Component B, posteriorly.

In this process, before sending Component A to accumulators, it is necessary obtain a homogeneous mixture, otherwise there will be problems, particularly during the sealant application, and later will not have the desired appearance or required properties. For that, in the extruder start up it is necessary a waiting time until obtaining the desired mixture, and from there forward to the accumulators. During this waiting period, what happens is scrap production, because everything that is produced and it is not homogenous, it is considered scrap.

This process involves many variables, so it is necessary making a study about the most important ones, and finding an alternative to produce less scrap during the start up. This will also leads to an increase in process efficiency and a less raw materials waste.

Table 1 – Masterbatch composition

Materials	(wt.%)
Butyl Polymers	60.5
Carbon Black	21.2
Zinc Oxide	3.1
Aliphatic Resin	12.2
QDO	2.2
Sulfur	0.9

2.3 Component B

Component B is a mixture of polybutene with organic peroxides, and is made in a mixing tank at room temperature and pressure, having the purpose to activate the QDO present in Component A. The peroxides used are two, TBPB and BPO, with different activation temperatures. TBPB has an activation temperature of 120 ºC, where the activation occurs during the sealant application, and BPO has an activation temperature around 90 ºC, where is activated after the sealant application.

2.4 Sealant

Most of the damages in a tire occur in the tread area, if a tire losses air there is great risk of failure. Whit the technology present in a ContiSeal tire, this have a flexible and sealant layer around the internal part, which runs from shoulder to shoulder of the tire, Figure 5. This application has countless advantages, including an increase of mobility, security and resistance from damage to about 85 %.

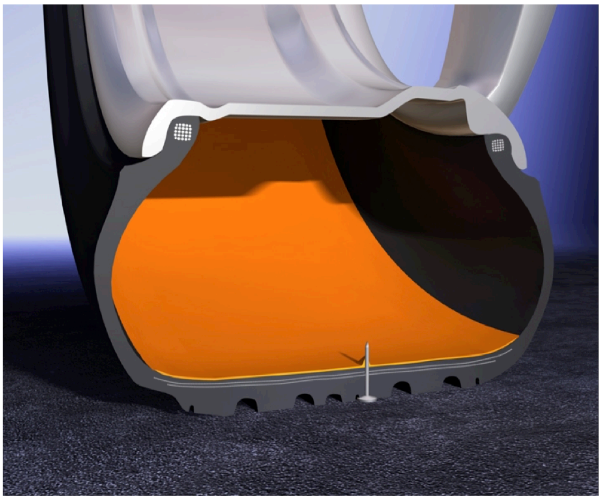

Figure 5 - The ContiSeal layer (extracted from [2])

As stated before, the sealant applied is a mixture of two components, Component A and Component B, in a ratio of 10,3:1 (v/v%), respectively. The purpose of this mixture is the formation of a crosslinking compound, leading the sealant to have a balance between viscous and elastic properties, making it a viscoelastic material. The viscosity part is responsible for allowing the sealant to adhere to the tire and to flow enough so it is possible for it not only stick to the puncturing object but also to create another airtight seal at the puncture site when the object its remove. The elastic part, is what assures the long term seal integrity, avoids the flow of material away form the applied area and through the large holes left behind by dislodged objects and also assures the high air impermeability. In Figure 6 and Table 2, it is possible to observe the boundary conditions for the sealant and his composition, respectively.

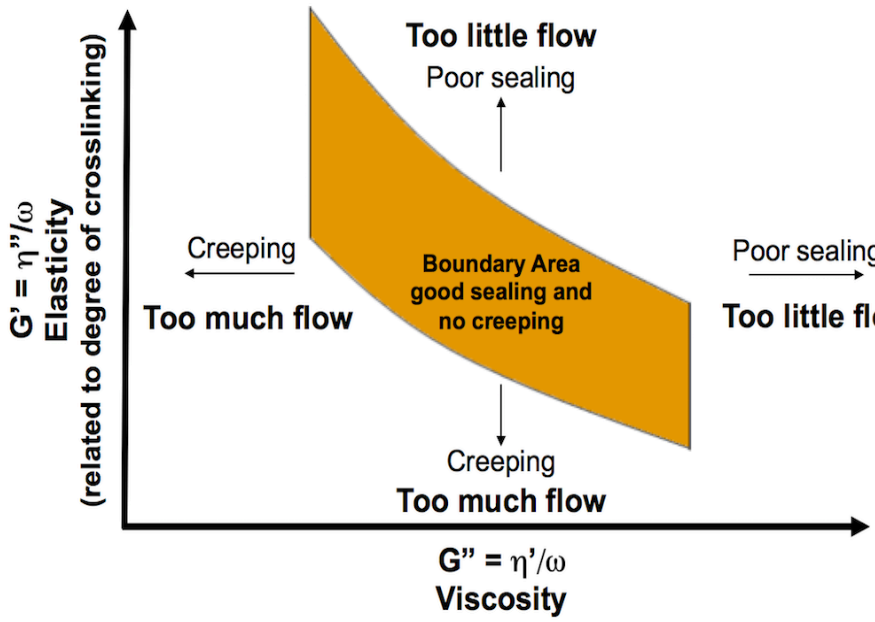

Figure 6 - Boundary conditions for sealant used in ContiSeal (extracted from [2])

Table 2 – Sealant composition[2]

Material	Sealant Relevant Properties
Butyl Polymers	High air impermeability, resistance to flow at high temperature and resistance to oxidative aging
Carbon Black	Low loading of black provides reinforcement at low strain without loss ultimate elongation and reaction sites for the quinone curing system
Paraffinic Oil	Process aid to improve flow of material through equipment
Aliphatic Tackifier	Provides adhesion of sealant to tire of sealant to penetrating object
Liquid Polymer Tackifiers	Provides extremely high tack over a wide temperature range, optimum flow properties needed for sealant and high elongation without break
QDO	Provides age resistant crosslinks which maintain the material properties over long service life of the tire
Zinc Oxide and Sulfur	Provides high temperature stability to the crosslinking network
Peroxides	Responsible for the QDO activation in crosslinking reaction

The sealant crosslinking reaction starts with formation of peroxide radicals due to the heat. These radicals will converter QDO into para-dinitrosobenzene, Figure 7, this is the agent responsible for the crosslinking reaction. Then, this agent will react with the isoprene chains present in Component A, causing the crosslinking reaction, Figure 8. The peroxide activation occurs at high temperatures, while the crosslinking reaction occurs at around 50 ºC, hence the use of two different peroxides. This lower reaction temperature will increase the crosslinking degree, since when the tire is already storage the reaction is still on going.

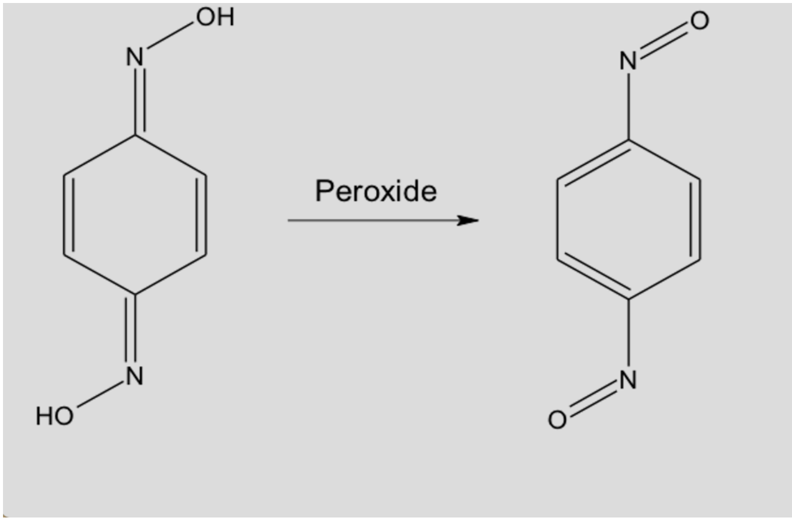

Figure 7 - Conversion of QDO into para-dinitrosobenze (extracted from [2])

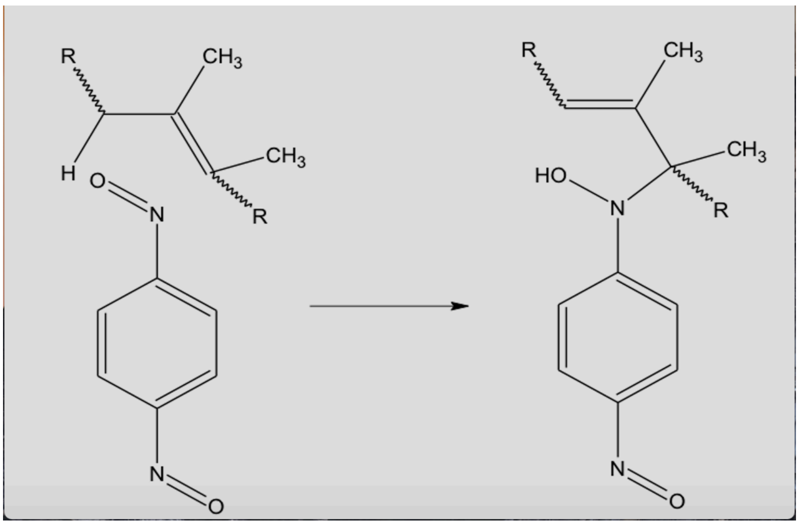

Figure 8 - Crosslinking reaction between isoprene and para-nitrosobenzene (extracted from [2])

The mixture of the components is made up through a dosing system, in Robot's mixing chamber, which will apply the sealant in the tires, Figure 9, where there are three Robots in ContiSeal.

Figure 9 - Robot used in ContiSeal process

However, during the application can happen many problems, lack of tires, dosing program error, or even a tire article setup, which will lead to scrap production, because the components can not stay for too long in the mixing chamber, originated high pressures, causing the Robot, for security reasons, to flush the mixture inside. Therefore, the Robots are another source of scrap.

For a possible reuse of this scrap material, since it is in good condition to be reapplied, it was study over an undetermined time at a temperature around 90 ºC, for how long the material can be constantly heated without losing is properties.

2.5 Viscoelastic

Viscoelastic materials, is a class of materials that exhibit both viscous and elastic properties. When a force is applied, called shear stress, to a volume of material, a displacement occurs, know as deformation or strain. In a viscoelastic material, some of the deformation caused by shear stress, is elastic and will return to the original shape when the force is removed. The remaining deformation, viscous part, will not return to the original shape when the force is removed, and it will dissipate the energy as heat.[7];[8] In Figure 10, is possible to observe the shear stress applied to a material, resulting in displacement.

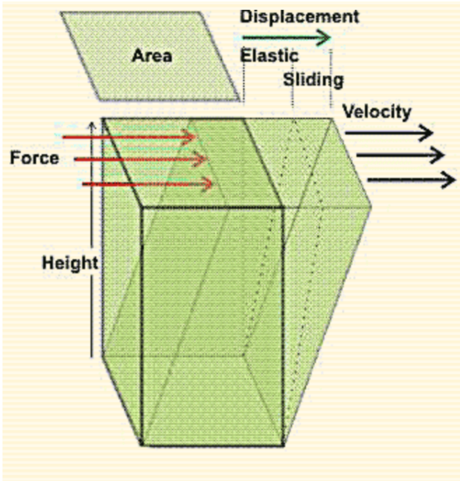

Figure 10 - Shear stress applied to a material along with the resulting displacement (extracted from [7])

The shear stress is given by equation (1), strain and shear strain rate by equation (2) and equation (3), respectively. The viscosity is obtained by equation (4).

$$\sigma = \frac{F}{A} \tag{1}$$

$$\gamma = \frac{\Delta x}{H} \tag{2}$$

$$\dot{\gamma} = \frac{\Delta x}{H \Delta t} \tag{3}$$

$$\eta = \frac{\sigma}{\dot{\gamma}} \tag{4}$$

,where F is the force applied, A is the area, Δx is the displacement, H is the height and Δt is the duration of the applied force.

One way to evaluate the viscous and elastic parameters is by a harmonic oscillation test, in what shear stress (σ_0) and strain (γ_0) vary with the time, Figure

11.The phase angle (δ) is also an important value, evaluated the material properties.Error! Reference source not found.

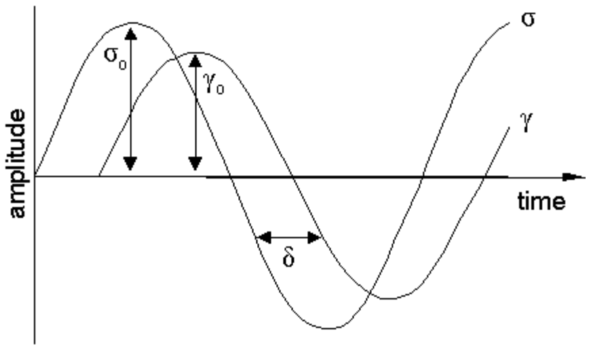

Figure 11 - Sinusoidal wave for shear stress and strain (extracted from [1])

To an ideal elastic solid, $\delta = 0°$, the material is purely elastic and considered in phase, as for a purely viscous, $\delta = 90°$, the material is liquid and out-of-phase. The ratio between the shear stress and the strain, gives the shear modulus known as G, and it is related to the hardness of the material. This modulus is resulting from changing strain and can be expressed in terms of a complex number, with a real part and an imaginary part, Figure 12.[7]

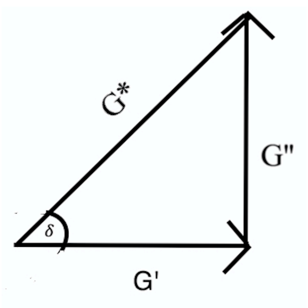

Figure 12 - Vectorial representation from modulus

The storage modulus, represent the real and elastic part of material in oscillation movement, equation (5).

$$G' = \frac{\sigma_0}{\gamma_0} \cos \delta \tag{5}$$

The imaginary part, correspond to viscous and it is called the loss modulus, equation (6).

$$G'' = \frac{\sigma_0}{\gamma_0} \sin \delta \tag{6}$$

Therefore, the complex modulus is defined by equation (7).

$$G^* = \frac{\sigma_0}{\gamma_0} \cos \delta + i \frac{\sigma_0}{\gamma_0} \sin \delta \tag{7}$$

$$G^* = G' + iG''$$

Equation (8) is obtained from equation (5) and equation (6) after mathematical manipulation.

$$\tan \delta = \frac{G''}{G'} \tag{8}$$

, tan δ gives information about the material composition; if the value is below the unit, means that $G' > G''$, which results in a hardness material, and the elastic part is higher. If $\tan \delta$ is higher than the unit, means $G'' > G'$, the material has a liquid comportment and the viscous part is higher.[7]

Following the complex relationship above, it is also possible to obtain the complex viscosity, Figure 13. Where shear stress is divide in viscous stress and elastic stress, resulting from changing stress.[7]

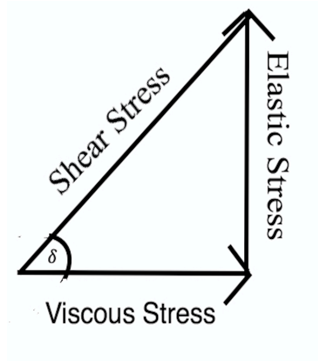

Figure 13 - Vectorial representation of shear stress

As in previous case, the viscous complex will have a real part, η', and an imaginary parte, η''. Taking the real part calculation as example, known as dynamic viscosity. **Error! Reference source not found.**

$$\eta' = \frac{shear\ stress\ (in\ phase)}{shear\ strain\ rate} \tag{9}$$

, where the shear stress in phase, is the elastic part in Figure 13, $\sigma_0^* \sin\delta$, and the shear strain rate is given by equation (10).

$$\dot{\gamma}^* = \gamma_0^*\ \omega \tag{10}$$

Equation (9), then will result in equation (11).

$$\eta' = \frac{\sigma_0^* \sin\delta}{\gamma_0^* \times \omega} = \frac{G^* \sin\delta}{\omega} = \frac{G''}{\omega} \tag{11}$$

The viscous in imaginary part, is given following the same procedure as before, resulting in equation (12).

$$\eta'' = \frac{G'}{\omega} \tag{12}$$

3 Experimental

3.1 Operating Conditions

As previously stated, the purpose of this project was the reduction and study the conditions to reuse the scrap material in ContiSeal process, where were analyzed two sources of scrap. One corresponded to production of Component A in a twin-screw extruder, and the second to sealant application in the tires.

In first case, the variables possible to control were, barrels temperatures, throughput, screw speed, internal pressure and recipe values. Due to the time limitation, it was decided controlling two of them, barrel temperatures and throughput. Starting with a gradual increase of the temperature in first barrel, as good results were obtained, was studied the throughput influence. After these parameters were well defined, the temperature in remaining barrels was increased, evaluating the results, taking into account the aspect and properties of the final product. After that, the temperature profile was introduced in the second extruder, thereby determining if the results were the same as in the first one.

Meanwhile for the study of reuse the sealant scrap, the objective was to evaluate for how long the material can be constantly heated, without losing its properties, to be reapplied on a possible reuse process.

3.2 Design of experiments

Having established the variables to study, it was necessary proceed to the realization and study of the experiments, obtaining information about the selected variables.

For the extruder experiment, the study was first conducted with its initially temperature profile, Figure 18, evaluating the usually scrap production in start up. Then, the first barrel temperature was increased to 95 ºC. As during the study there were good results, was introduced the analysis of the second variable, throughput.

Starting with a slower throughput, 2500 cm^3/min, evaluating that the impact was negative, was increased to 3200 cm^3/min, concluding that was the ideal throughput for the start up, achieving a good mixing. After the stabilization of these two variables, was analyzed the temperatures of the following barrels, thereby trying to get even a lower scrap production at start up. For that, the barrels temperatures, where mixing elements are present, were increased, since these elements are responsible for a good homogenization. As the results were good, it was decided to increase the temperature on the remaining barrels, achieving a good performance. Then, was performed one last run, increasing the throughput to 3400 cm^3/min, assessing the influence of this parameter with the new temperature profile. Established the temperature profile, it was next applied to the second extruder, verified if the same results were obtained as in the previous extruder. Furthermore, throughput was also varied, since this parameter is a slightly different in the two extruders.

At the end of this study, it was made a comparison between the realization time of the project and the values of viscosity and frequency obtained for the same time, in laboratory tests, observing whether the product during this time was within the proposed limits. The test conducted at the laboratory was Frequency Sweep, which is performed daily by the operators.

As for the study of sealant scrap, since this material is in good condition to be reapplied, it was necessary to know for how long it can be heated, without losing their properties to be used again. Where a sealant sample was placed at 90 ºC for a certain time, analyzing over the days its viscosity and tan δ, evaluating if were within the proposed limits. The test conducted for this study, was Stress Sweep, which is also made daily by the operators.

3.2.1 Testing Procedure

Frequency Sweep allows to evaluating the complex viscosity of Component A, achieving if the dosing between Masterbatch and polybutene is being properly done, and the pre-crosslinking degree. Previous studies indicate that when using Frequency Sweep, the frequency which occurs the maximum value for η'' allows to identify the occurrence of pre-crosslinking.

In Table 3 and Table 4, are indicated the operation conditions for this test and the proposed limits, respectively

Table 3 - Operation conditions for Frequency Sweep

Pressure (Pa)	100 Pa
Frequency (Hz)	100 a 0.01
Temperature (°C)	120 ºC
Time (s)	3000
Gap Size (mm)	0.5

Table 4 –Target and limits for Frequency Sweep

	η^* (Pa·s)	η'' max (Hz)
LTL	405	
LAL	425	
Target	555	0.20
UAL	685	0.38
UTL	705	0.40

Stress Sweep allows to assessing the crosslinking degree of sealant, as well as the compound behavior of viscoelastic properties at room temperature, through the complex viscosity and tan δ. In Table 5 and Table 6, are indicate the operation condition and proposed limits for Stress Sweep, respectively

Table 5 - Operation condition for Stress Sweep

Pressure (Pa)	50 a 500
Frequency (Hz)	1
Temperature (°C)	30
Time (s)	480

Table 6 - Target and limits for Stress Sweep

	η *(kPa·s)	tan δ
LTL	2.3	0.55
LAL	2.5	0.57
Target	3.9	0.65
UAL	5.3	0.73
UTL	5.5	0.75

The software program defines the gap size, according with the sample height, were the value obtained for viscosity and tan δ varies with the gap size. Therefore, it is necessary to test at least five samples for defining a regression line between the gap size and the complex viscosity by evaluating the correlation coefficient obtained. Complex viscosity is then calculated using the regression equation for a gap size of 3 mm, where this is the mean value for sealant height when applied to the tire.

3.3 Extruders and Laboratory Unit

The tests regarding the extruders start up were performed in a twin-screw extruders, with a Masterbatch downstream feeding, three polybutenes downstream feeding and a paraffinic oil downstream feeding, Figure 14.

Figure 14 – One of the extruder used in this project

The process control is performed in a display, where it is possible to control the variables studied in the project, barrels temperature and throughput, along with others, Figure 15.

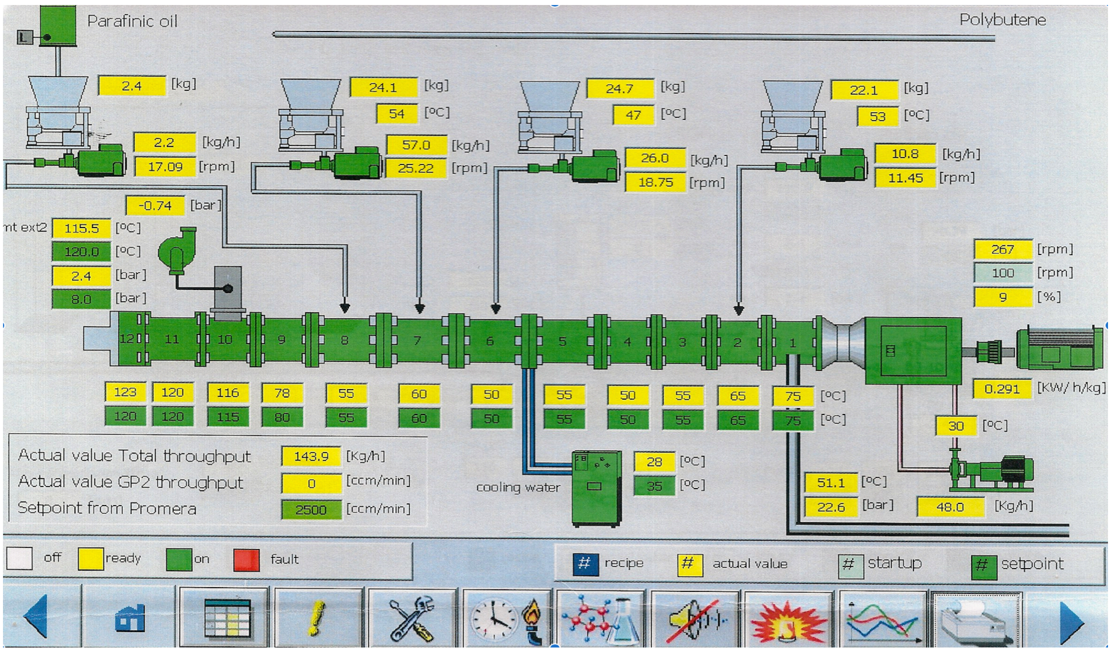

Figure 15 – Extruder process control

From monitoring it is also possible to notice the performance over time in a graphical analysis. Observing a larger range of variables, specific energy inside the extruder, barrels and polybutene temperature, internal and die pressure, easily noticing when a problem occurs.

Concerning the laboratory tests performed on Component A and sealant analysis, it was used a rheometer RheoStress ThermoScientific 6000, Figure 16.

Figure 16 - Rheometer used in laboratory tests

The software used was RheoWin Job Manager, where it is possible to select the program according to the purpose, Figure 17.

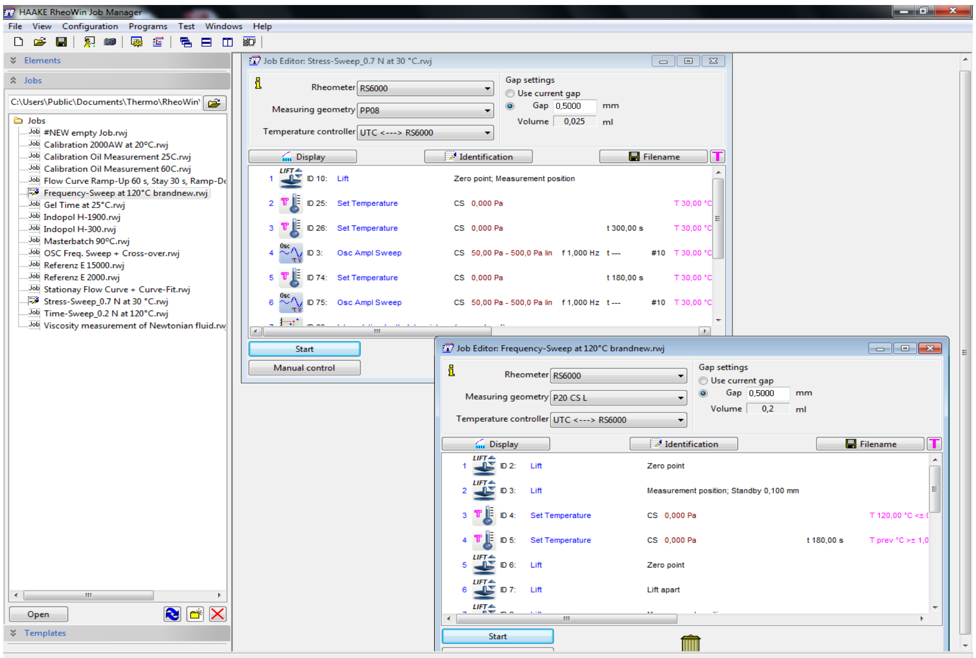

Figure 17 - Software and programs used for the laboratory tests

4 Results and Discussion

4.1 Extruders

The study performed in ContiSeal extruders, had as objective the scrap reduction during the start up of Component A production. As previous stated, the variables studied were barrels temperature and throughput. The pressures for the two extruders were always constants, 9 bar and 10,5 bar, respectively. In Figure 18 and Figure 19, it is possible to notice the study initial temperatures and the throughput, and the start up graphic, respectively.

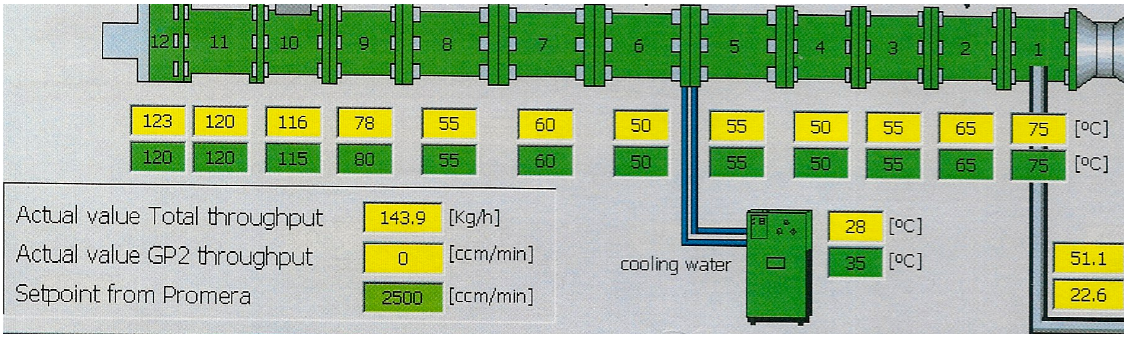

Figure 18 – Temperature profile and throughput value for first run

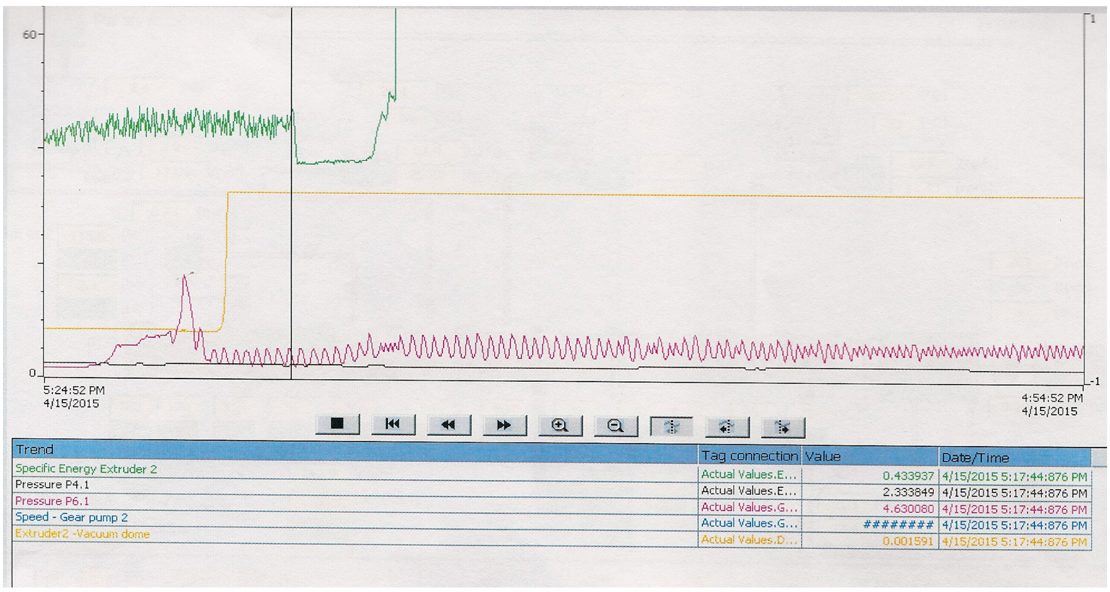

Figure 19 – Specific energy value for first run

From Figure 19, it is observed that the applied specific energy is very high, 0.45 kWh/kg, when its optimum value is about 0.27 kWh/kg, and as previously mentioned, a higher specific energy leads to a poor mixing. To decrease the power applied, a certain waiting time is needed, in which, during this time, there will be scrap production. In Table 7, it is indicated the start up total time and the amount of scrap produced in first run, as well as the first barrel temperature and throughput values.

Table 7 – Values obtained for first run

First barrel temperature (°C)	75
Throughput (cm^3/min)	2500
Total time (min)	28
Total Scrap (kg)	30

Given this profile, as earlier stated, was started by gradually increase the first barrel temperature for the following three runs, and in the last one was increased the throughput. In Table 8, the values obtained are presented for the runs stated above. In Figure **20**, it is indicated the specific energy for forth run, when the throughput was increased.

Table 8 – Values obtained for second, third and fourth run

	2nd Run	**3rd Run**	**4th Run**
First barrel temperature (°C)	80	85	90
Throughput (cm^3/min)	2500	2500	3200
Total time (min)	12	16	14
Total Scrap (kg)	12.9	16.8	17

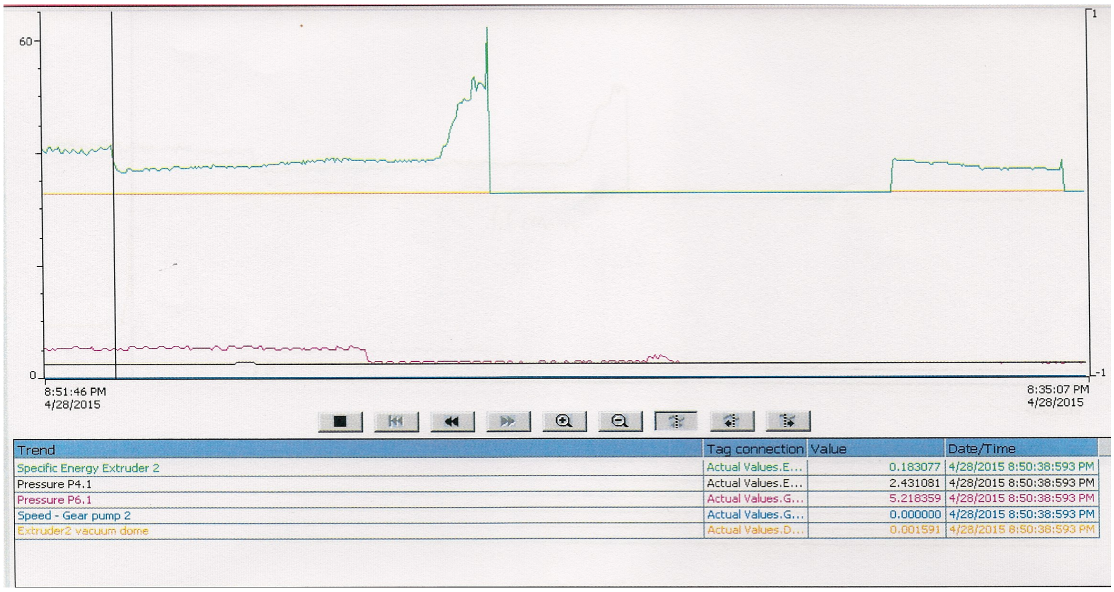

Figure 20 **– Specific energy value for fourth run.**

In Figure **20**, it is noticed that the specific energy for the forth run, initially, is about 0,20 kWh/kg, increasing approximately to 0,26 kWh/kg. With this, it shows that an increase in extruder throughput, leads to a shorter specific energy value, since the material is less time inside the extruder, leading to a reduce. Despite this, the amount of produced scrap is lower in the second run, as indicated in Table 8, with a slightly difference compared to forth run. This may depend on the operator during the start up moment, as the mixture is considered homogeneous through visualization, or, in fourth run, although, having a higher throughput and a higher screw speed, which results in a better mixing, this will lead too to an higher speed of scrap production. The same happens compared the third with the forth run, a higher throughput leads to a shorter time but could lead to a higher scrap production.

In next runs, it was established the first barrel temperature at 95 ºC, deciding to increase the temperature in the following barrels, while the throughput value was kept constant at 3200 cm^3/min. On the fifth run, the third and fourth barrel temperature was increased, at 5 ºC and 10 ºC, respectively, as in section there is mixing elements, Figure 21. In Table 9, is presented the values obtained for this run.

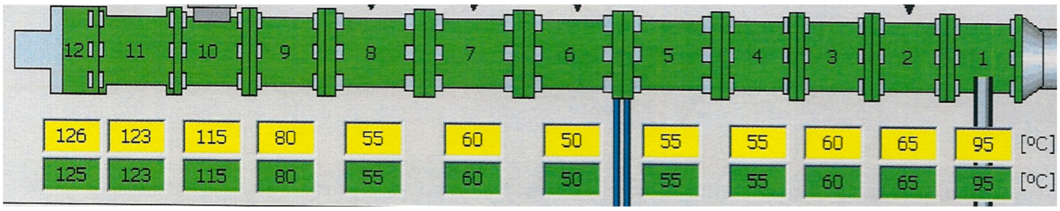

Figure 21 – Temperature profile for fifth run

Table 9 – Values obtained for fifth run

First barrel temperature (°C)	95
Third barrel temperature (°C)	60
Fourth barrel temperature (°C)	55
Throughput (cm^3/min)	3200
Total time (min)	12
Total Scrap (kg)	15

Despite the increase in temperature over two barrels, there was no great difference in the scrap production during the start up. This may be do to the fact that there was not given sufficient time for the screw to heat, between the rise in barrels temperatures and the extruder start up.

About sixth run, the increase in temperature was made in sixth and eighth barrel, at 10 °C and 5 °C, respectively, Figure 22. In the sixth barrel there is also the presence of mixing elements and the second polybutene downstream feeding, reason for increasing the temperature and obtain a better mixing. The eight barrel, although there are no mixing elements, is where the third polybutene downstream feeding is located, allowing a better mixing too. In Table 10, is presented the values obtained at sixth run.

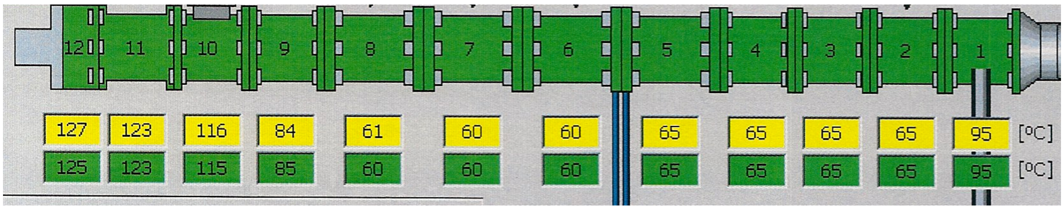

Figure 22 – Profile temperature for sixth run

Table 10 – Values obtained for sixth run

Sixth barrel temperature (°C)	60
Eighth barrel temperature (°C)	60
Throughput (cm^3/min)	3200
Total time (min)	9
Total Scrap (kg)	9.2

Noticing the Table 10, concludes the huge difference in scrap produced between the run in question and the first one, with a difference of about 70 % between the two runs. This result shows the influence of temperature in scrap production during the start up. Considering this value as very close to the minimum possible to scrap production during the start up, it was decided to perform another run about the throughput influence, increasing its value to 3400 cm^3/min. The first barrel temperature was decreased at 10 ºC, Figure 23. In Table 11, is shown the obtained values.

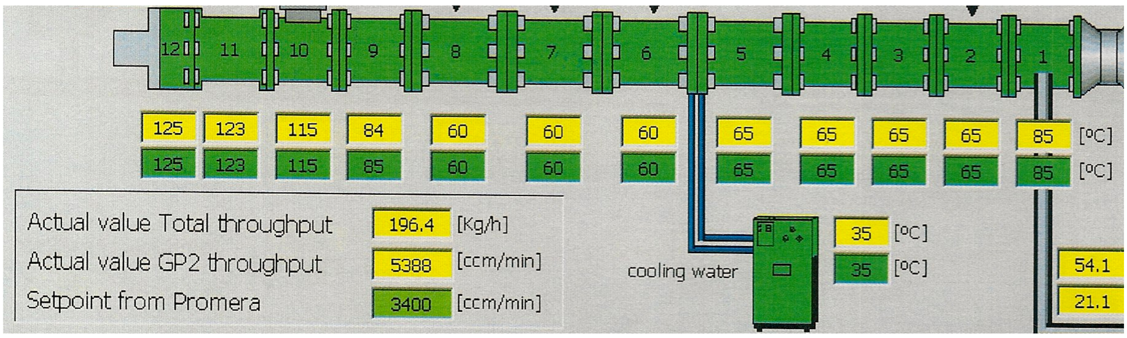

Figure 23 – Temperature profile for seventh run

Table 11 – Values obtained for seventh run

First barrel temperature (°C)	85
Throughput (cm³/min)	3400
Total time (min)	17
Total Scrap (kg)	32.7

By Table 11, it is observed that increasing the throughput the results obtained are not the best ones. Reason for this may be due to the fact that increase the throughput will lead to an increase in screw speed and in scrap production. As previous stated, an increase in screw speed would lead to a poor mixing. Although, it can depend of other reasons, namely, the formation of pre-crosslinking reaction, by increasing the throughput it will lead to an increasing in temperature, resulting in pre-crosslinking, as it will be explained later.

After the conclusions reached about the first extruder, it was decided to apply the same temperature profile to the second extruder in ContiSeal, making sure the results obtained were the same. Considering this as the eighth run, the temperature profile is pretty much the same, except the second barrel temperature, which is higher 10 ºC. Since this value was already inserted in the second extruder, was decided to keep it, evaluating in this way the effect that may have. Furthermore, the throughput recommended for this extruder was 3000 cm^3/min, since this is more stable with this value. In Figure 24 and Table 12, are presented the temperature profile and values obtained for this run, respectively.

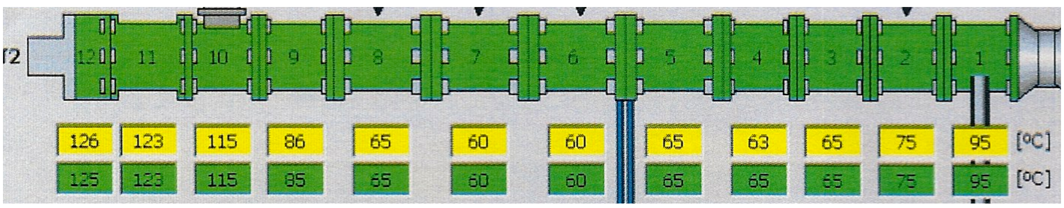

Figure 24 – Temperature profile for eighth run

Table 12 – Values obtained for eighth run

Second barrel temperature (°C)	75
Throughput (cm^3/min)	3000
Total time (min)	12
Total Scrap (kg)	9.8

It was expected with a lower throughput, will take a little longer to obtain a homogenous product, thereby producing a little more scrap compared to the sixth run. Nevertheless, it concludes that the temperature profile used results in both extruders, getting a good start up. However, still was performed two more runs in this extruder, now varying the throughput even expect for an instability in the process, as previously stated.

In the ninth run, it was decided to decrease at 5 °C the first barrel temperature from the previous run, find out if there was need for such a high temperature. The throughput used in this run was 2770 cm^3/min. In Figure 25 and Table 13, are presented the temperature profile and values obtained for this run.

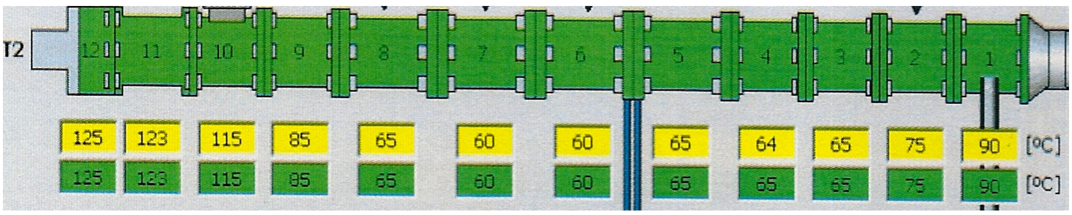

Figure 25 – Temperature profile for ninth run

Table 13 - Obtained values for ninth run

First barrel temperature (ºC)	90
Throughput (cm^3/min)	2770
Total time (min)	14
Total Scrap (kg)	11

Like in the previous run, it was expected that a decreased in throughput cause an increased in start up total time and a larger amount of scrap produced. However, the decrease at 5 ºC in first barrel temperature, did not cause wide variation, leading, in next run, to another temperature decrease in first barrel, at 5 ºC, and a decrease in second barrel temperature at 10 ºC, evaluating the effect. In the next run, the last one, the throughput was increased to 3200 cm^3/min. In Figure 26 and Table 14 are shown the temperature profile and the values obtained for the tenth and last run.

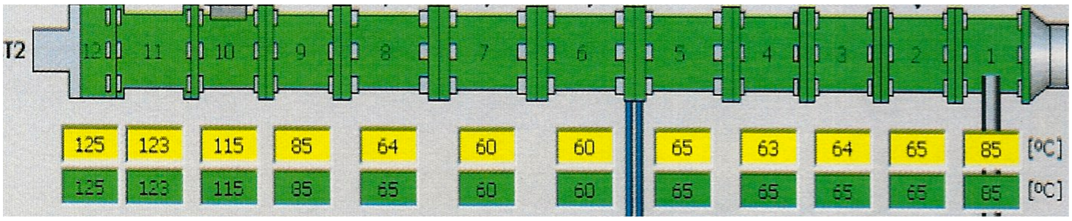

Figure 26 – Temperature profile for tenth run

Table 14 - Obtained values for tenth run

First barrel temperature (°C)	85
Second barrel temperature (°C)	65
Throughput (cm^3/min)	3200
Total time (min)	10
Total Scrap (kg)	8.6

As it can be noticed from the Table 14, this run was the one with the best results, very close to the sixth run, proving that this temperature profile works in both extruders. Although, it is noted that with equal throughput, the start up total time of tenth run is superior to the sixth run, and the scrap produced is slightly smaller. This is due to the relationship between throughput and screw speed settings, as previously explained. In this case, although an equal throughput, the screw speed of the second extruder is inferior compared to the first extruder, leading to a longer start up total time, but achieving with this a little less scrap, since there is a better mixing.

After this analysis, it was observed that considering only two variables, is possible to reach good results, being necessary to find a good relationship between them, otherwise it would be very difficult to obtain the best final product.

4.1.1 Laboratory Tests

Despite the good results obtained with this study, there are certain limits that must be accomplish for Component A can be used properly. In a working day, three tests are made, one per shift, evaluating the value of the viscosity and pre-crosslinking degree, wherein the course of this study, there were times where the viscosity was high as well low, in both extruders, Figure 27 and Figure 28. The study was conducted between 15/04/2015 until 16/05/2015.

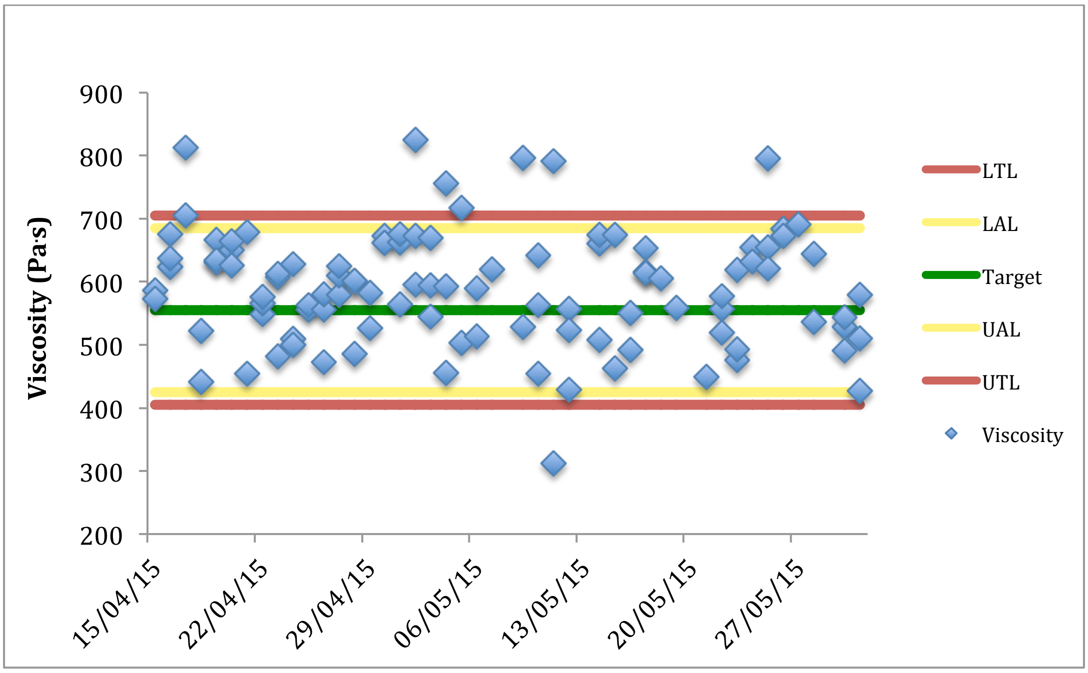

Figure 27 - Viscosity values over the study for the first extruder.

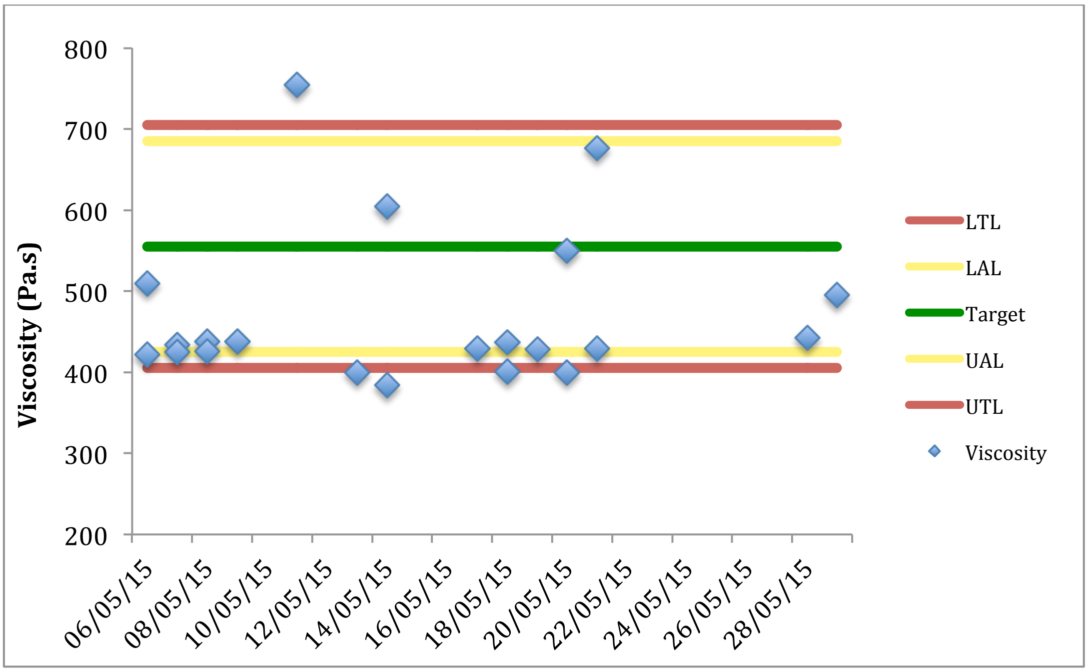

Figure 28 - Viscosity values over the study for the second extruder.

The first extruder has more viscosity measurements, because it is used more often than the second extruder. By analyzing the two previous figures, it is noticed that during certain phases of the study the viscosity values obtained were high and low, and after completing the study are few the times that viscosity value was off the limits. Since this is a process that involving many variables, it is difficult to conclude the reason for such results, and in one hand was to be expected that with the increase in barrels temperature, the final product would be more liquid, which may be the reason to obtain lower viscosities. In the other hand, the increase in barrels temperature may lead to pre-crosslinking reaction between the isoprene chains with QDO and sulfur, leading to a higher viscosity, failing to obtain a good mixing.

As for the pre-crosslinking value, by Figure 29 and Figure 30, it is possible to observe that the results are within the limits, however the parameters established may not be the best, as there is no minimum values. Giving this, it will always be considered that there is no formation of pre-crosslinking reaction, when most likely there are, as previous stated. Moreover, many variations are also observed indicating that the parameters or the method used for this determination may not be the best, since sometimes the frequency value is not obtained in the program, considered in those cases a value of 0,10 Hz. In these cases, when the frequency values are low or are not obtained, but the viscosity value is good, the product is considered acceptable. By placing a minimum value, the critical sense would be higher, as the information obtained.

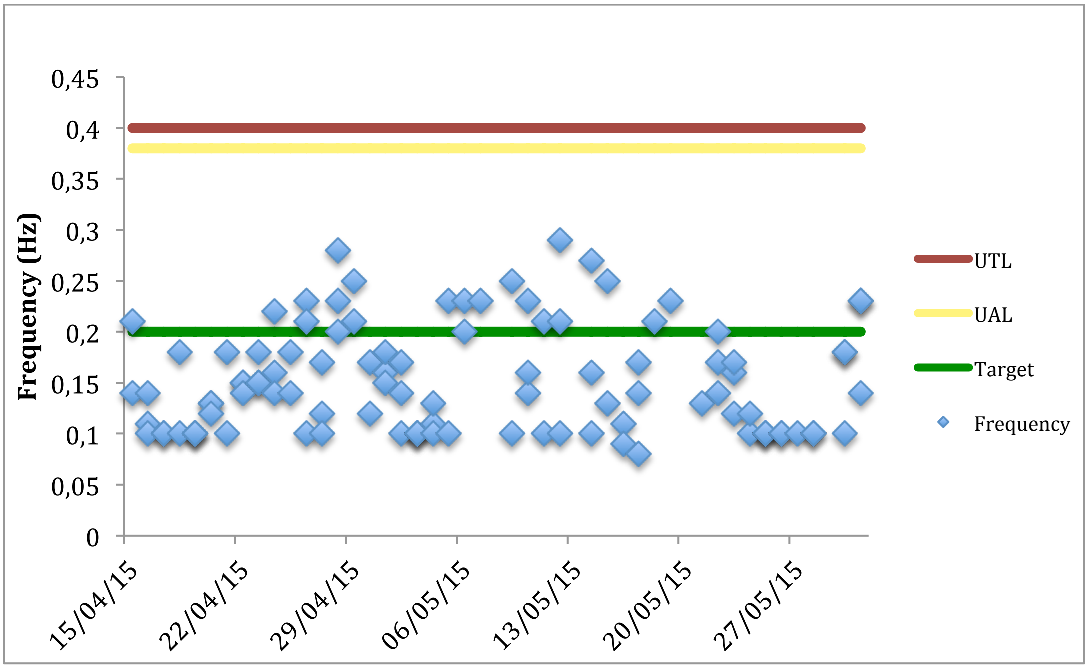

Figure 29 – Frequency values over the study for the first extruder

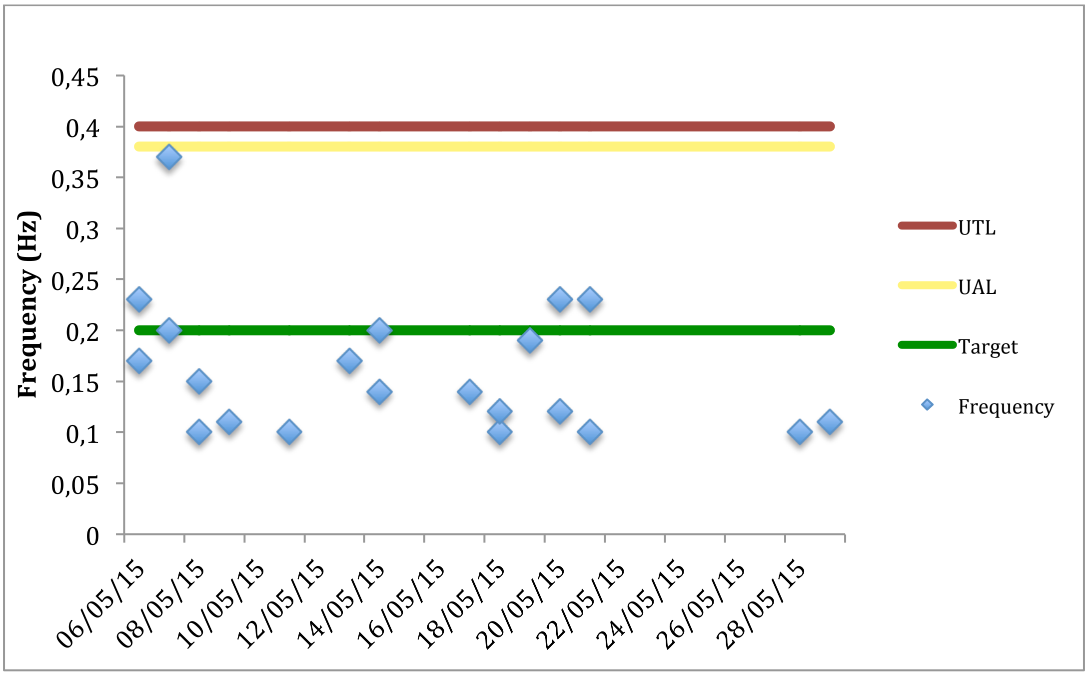

Figure 30 - Frequency values over the study for the second extruder

After analyzing the laboratory results, comes to the conclusion that a scrap reduction is possible, however the material may not have been the best. It is necessary to find a relationship between the increase in barrels temperature and the desire properties for the material, achieving this way the ultimate purpose. Since in this study were only considered two variables, there are other ones still to be analyzed, and another factors that may influence the reduction in scrap production, in particular the extruder length, as well as the ratio between extruder start up and shutdown. Controlling this ratio will avoid unnecessary start up's and unnecessary scrap production.

4.1.2 Cost Reduction for Extruders

Despite a scrap reduction is the proposed objective, a cost reduction is also a great advantage that can be obtained. Considering a scrap reduction of 70% and the scrap sales price of 107.5€ a tonne, by equation (13) is possible to calculate the cost reduction in the three months of study, indicating the results in Table 15.

$$Cost\ Reduction = \frac{Reduction\ in\ month}{1000} \cdot 107.5 \tag{13}$$

Table 15 – Scrap production, reduction and cost reduction in the extruders

	Scrap Production (kg)	**Scrap Reduction (kg)**	**Cost Reduction (€)**
March	2323	1626.1	174.8
April	1471	1029.7	110.7
May	4274	2991.8	321.6

Assuming the monthly cost reduction as the average value of the three months from Table 15, in the end of one year the scrap cost reduction in the extruders is €2428.4.

4.2 Sealant

The study on the conditions to reuse the sealant scrap material, had as purpose to analyze its properties over the time, being constantly heated. For this study, was considered that when scrap is being generated, it will be placed in a heated accumulator with a capacity of 200 kg. As previously stated, the application process is done by three Robots, leading to a large amount of scrap production. Although seem otherwise, the scrap caused by this source is higher than the scrap caused by the extruders, Table 16

Table 16 – Scrap quantity produced by extruders and robots

	Scrap Quantity - Extruders (kg)	Scrap Quantity - Robots (kg)
March	2323	3430
April	1471	3507
May	4274	4683

At least during the three months of this project, the amount of scrap produced due to the Robots was superior to the produced by extruders, indicating the importance of reuse this material. In Table 17, is indicated the average time, in days, that each Robot takes to make about 200 kg of scrap, during the months of March, April and May.

Table 17 – Scrap production average time, in days, for the months of March, April and May

	March	April	May
Robot 1	6.25	5.20	3.83
Robot 2	3.75	3.25	2.70
Robot 3	5	6,20	5

As the average time never exceeds seven days, was only considered for the study a maximum time of seven days. By Figure 31 and Figure 32, is possible to notice the evolution of viscosity and tan δ during the seven days, proving that the values are within the established limits.

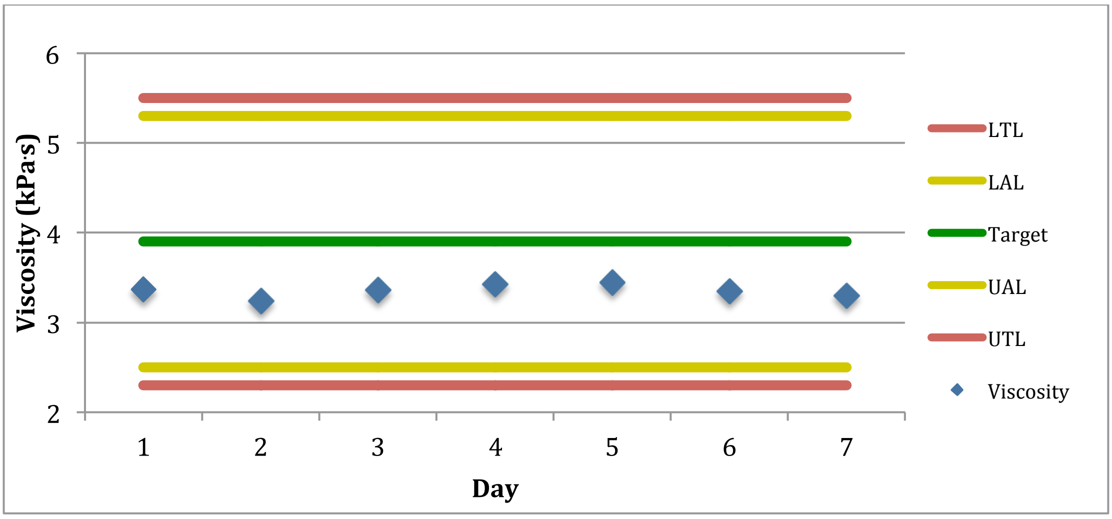

Figure 31 – Viscosity analysis over seven days

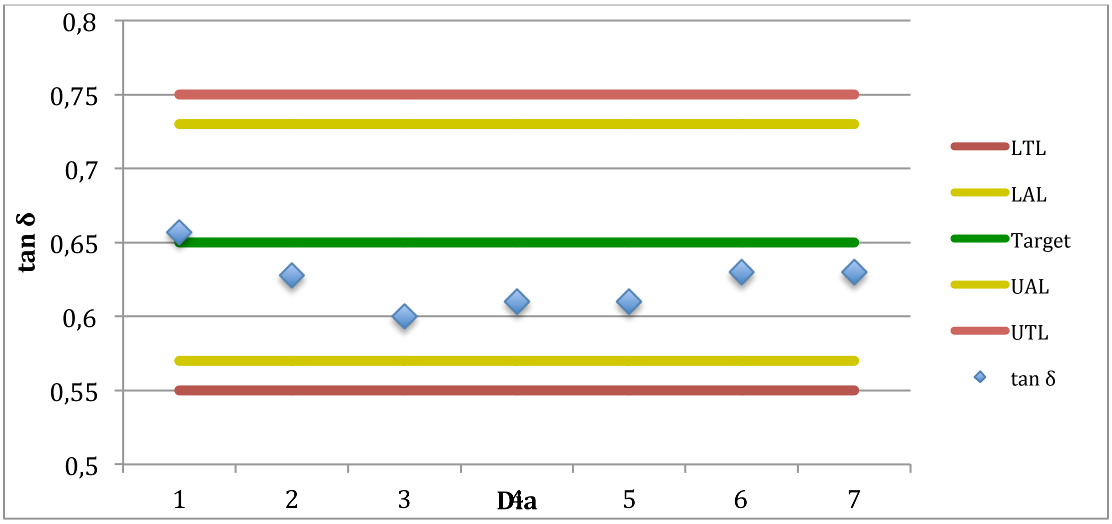

Figure 32 - Tan δ analysis over seven days

Assuming the average time according to Table 17, and 200 kg of total scrap as the accumulator maximum value, it is possible to know, approximately, how much scrap is reuse at the end of each month, in each Robot, equation (14).

$$Reusable\ quantity = \frac{N^{\underline{o}}\ of\ total\ days\ in\ the\ month}{average\ time\ to\ fill\ the\ accumulator} \cdot 200 \tag{14}$$

Table 18 – Total quantity of reuse scrap in each month

	March	April	May
Robot 1	992	1154	1619
Robot 2	1653	1846	2296
Robot 3	1240	968	1240
Total (kg)	3885	3968	5155

From Table 18, the values obtained for the total scrap reuse are slightly above to the values from Table 16. The difference between these values is due to the fact that the average time, in Table 17, is not being calculated for the exact total number of days of the month, but for a shorter number, resulting that the values from Table 18 are higher. However the values from Table 16, are the real ones, and the values from Table 18 show that it is possible to reuse all the scrap material from sealant application. Moreover, considering that an average sealant weight in a tire is 1,3 kg, to consume 200 kg is only necessary 154 tires, since the daily production is approximately 4500 tires, easily all the material is reused. With this, at the end of the month, on average value, is achieved a harnessing of about 4000 kg sealant.

If in any situation the average time exceeds seven days, it always possible to reuse the product, even has not reached the accumulator volume limit, just being careful to not exceed the considered limits for the properties. It can also happen, in some situations, the product is not within the proposed limits for the properties, even though is in average time limit, in these cases one of the alternatives is to apply it in a tire that is destined to ContiSilent market, as for this market the sealant purpose is not as rigorous as the previous one, and it is only need to test the product effectiveness in this type of tires.

After these results, it is always possible to obtain a complete reuse of this scrap material produced in the Robots, leading to higher process efficiency and lower amount of total scrap.

4.2.1 Cost Reduction for Sealant Application

As in the extruders case, can also be achieved a cost reduction in reuse of sealant scrap material. Considering that a reuse of 100 % of this material is possible and using the equation (13), is obtained the cost reduction of this scrap, Table 19. The scrap sales price is the same of the extruders.

Table 19 – Scrap production, reused and cost reduction in the sealant application

	Scrap Production (kg)	Scrap Reused (kg)	Cost Reduction (€)
March	3430	3430	368.7
April	3507	3507	377
May	4683	4683	503.4

Assuming also in this case the monthly cost reduction as the average value of the three months from Table 19, in the end of one year the cost reduction of the scrap sealant material is €4996.6.

5 Conclusion

This project had the purposed to study the reduction and the conditions to reuse the scrap generated at the ContiSeal process. The two scrap sources are the start up of the extruder for Component A production and sealant application to the tires.

In the first case, a reduction of about 70 % of scrap generation was achieved, although the material properties obtained at the end, sometimes, was off the proposed limits. The viscosity values obtained in laboratory tests, showed higher and lower viscosity compared to the target value. The same happened to the frequency values, indicating the possibility of pre-crosslinking formation, leading to greater mixing difficulties, as well as higher viscosities. Thereby concluding, that despite being achieved a significant reduction, it is necessary to take into account the final product quality, finding the best compromise between the variables under study with the required properties for final product.

As for the study of reuse the sealant scrap, it was evaluated if its properties remained within limits, even when is continuously heated at about 90 ºC, thereby allowing a reuse process days after it was produced. It was shown that, at least, at the end of seven days the properties are maintained, indicating that reusing it at least seven day after its production is possible. In addition, a complete reuse is achieved, and even if the material loses its qualities, it is possible that could be used in tires intended to ContiSilent market, through previously performed analysis.

In the end of the project, was established that it is not only possible to make the reuse of produced scrap, as well as a reduction in the production of it, with a total cost reduction of €7425 per year. However, this study was only a small part of what can be done and what can improve in the efficiency and optimization of scrap reduction in ContiSeal.

6 Project Assessment

6.1 Accomplished Objectives

The initial purpose for the thesis was, how to reuse the produced scrap, but, as previously stated, there were no possibilities or ways to do it. To overcome this, was proceeded to attempt the reduction in one of the scrap source, and the analysis of the possibility of reuse the scrap produced in the other source, managing to achieve these proposed objectives. As this thesis is the first study in this area, further analysis is still required to get better results, although the results here presented indicate that a reduction and a reuse are possible.

6.2 Limitations and Future Work

The main limitation was the time, since the start up of the extruder is often only done at least once a week, in addition there are others variables to be studied. As for future work is recommended to study the influence of others variables, besides the analysis of stipulated limits, in laboratory tests, to Component A. Thereby trying to achieve a reduction without the need of a reuse process. Furthermore, it would be a benefit build a scale model of the extruder, making a more complete study and less complicated, and in the end would be only necessary apply the results obtained to the real extruder.

Regarding the reuse of sealant scrap, after the analysis made in this study, is only required the construction of a process that allows the reuse process, taking into account the part of monitoring and process control.

6.3 Final Assessment

Both academically and professionally, this project was very interesting and challenging. Since as the good results started to show up it became more and more motivating besides the future contribution that can offer. On a personal level, it was a very enriching experience, where it was possible to develop several skills, as well as experience earned and contact with the entrepreneurial environment.

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